*Competency 1.1* **Radiation protection personnel shall demonstrate a working level knowledge of Department of Energy radiation protection program requirements as they relate to contractor activities.**

## 1. Supporting Knowledge and Skills

a. Discuss the role of the Department with respect to the contractor radiation protection programs as related to the following radiological control elements and requirements:

- Release of Radioactive Materials
- Transportation of Radioactive Materials
- Contamination Control
- Radiation Work Permits (RWP)
- Radiation Safety Training
- Source Controls
- Instrumentation and Calibration
- As Low As Reasonably Achievable (ALARA) Program
- Internal Dosimetry
- External Dosimetry
- Nuclear Accident Dosimetry
- Posting and Labeling
- Respiratory Protection
- Monitoring and Survey Equipment
- Records
- X-Ray Radiation-Generating Devices
- Internal Review and Audits
- Occurrence Reporting and Lessons Learned
- Organization and Administration
- Dose Calculations (internal/external)
- Biological Effects of Radiation
- Radiation Damage Mechanisms
- Shielding Design

## 2. Summary

**NOTE:** In addition to the material herein, it is highly recommended that an individual review materials, such as Cember, Gollnick, and/or Moe (see References in the Introduction section for reference information) on basic radiation protection.

DOE has the responsibility to establish radiation protection standards that are consistent with guidance developed by several interagency committees under the leadership of the Environmental Protection Agency (EPA). This guidance, approved by the President of the United States, is based on recommendations put forth by four principal scientific committees: the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the Committee on the Biological Effects of Radiation (BEIR).

DOE issued 10 CFR 835, *Occupational Radiation Protection*, as a means to implement the *Radiation Protection Guidance to the Federal Agencies for Occupational Exposure* (52 FR 2822) and codify existing DOE radiation protection directives. The final rule became effective 30 days after its publication on Dec. 14, 1993 in the *Federal Register*. This regulation establishes requirements for radiation protection of occupational workers at DOE facilities with the intent of ensuring that radiation exposures are kept not only within applicable limits, but as far below these limits as is reasonably achievable. Because DOE recognized that initially meeting the requirements of 10 CFR 835 would be difficult, the final rule required the submission of a radiation protection program (RPP) by Jan. 1, 1995 that would "set forth the plans, schedules, and other measures for achieving compliance" with the requirements of this final rule by Jan. 1, 1996. The RPP is designed to describe those actions that will demonstrate full compliance with 10 CFR 835.

Meeting the requirements set forth in 10 CFR 835 has been aided by the issuance of several implementation guides (IGs). The IGs serve to provide guidance and acceptable methodologies for implementing and conducting a variety of radiation-related programs. Existing implementation guidance exists in the following areas:

- Radiation safety training
- Workplace air monitoring
- Internal dosimetry program
- External dosimetry program
- Radiation protection program
- Occupational ALARA program
- Evaluation and control of fetal exposure
- Posting and labeling for radiological control
- Sealed radioactive source accountability and control

- Instrument calibration for portable survey instruments
- Occupational radiation protection recordkeeping and reporting.

10 CFR 835 does not address every essential area needed to form the basis of a comprehensive program to protect individuals from the hazards of ionizing radiation in the workplace. Therefore, DOE issued DOE Notice 441.1, *Radiological Protection for DOE Activities,* to establish radiological protection requirements that, combined with 10 CFR 835 and its associated implementation guidance, form the basis for a comprehensive RPP.

The DOE *Radiological Control Manual* offers detailed guidance for implementation of radiation protection in the DOE system. It establishes practices for the conduct of DOE radiological control activities and states DOE's positions and views on the best courses of action currently available in the area of radiological controls. This manual is intended to be reissued in 1996 as a RadCon Technical Standard. The use of "shall" statements presently in the document will presumably be changed to "should" (or equivalent) statements.

DOE Order 5480.4, *Environmental Protection, Safety, and Health Protection Standards,* provides a listing of mandatory and reference standards applicable to DOE and DOE contractor operations. Mandatory standards define the minimum compliance requirements applicable to the activities conducted by DOE and its contractors. Guides or standards under consideration as guidance documents and as a complement to mandatory standards are known as reference standards. The Order lists both types of standards under radiological and non-radiological categories. Several mandatory and reference standards are provided under the "radiation protection" category.

The aforementioned documents serve to satisfy DOE's role in ensuring that all aspects of their management and operating (M&O) contractors' RPPs meet and adhere to those requirements essential for protecting workers, the public, and the environment from all activities conducted under their auspices.

## 3. Self-Study Scenarios/Activities and Solutions

### Review

- 10 CFR 835, *Occupational Radiation Protection*
- DOE N 441.1, *Radiological Protection for DOE Activities*
- DOE/EH-0256T (Revision 1), *Radiological Control Manual*
- DOE Order 5480.4, *Environmental Protection, Safety, and Health Protection Standards*

- G-10 CFR 835, Revision 1, *Implementation Guides for Use with Title 10 Code of Federal Regulations 835*
- Cember, Herman (1996). *Introduction to Health Physics*
- Gollnick, Daniel A. (1991). *Basic Radiation Protection Technology*
- ("Moe") Argonne National Laboratory. (1988). *Department of Energy Operational Health Physics Training*


***Scenario 1, Part A***

On May 31, two workers employed at a DOE contractor facility were tasked with installing a new process line in an indoor building posted and controlled as a high radiation and high contamination area. This activity was infrequently performed. Both workers had completed Radiological Worker I training and additional training to allow them access into high radiation areas. Both workers were currently in compliance with 10 CFR 835 training requirements. However, one worker (Worker "A") required retraining effective the first day of the following month. The workers had been issued and had signed a Radiation Work Permit (RWP) limiting the scope of work to installing the new line in a shielded area of the building. The RWP required a full set of protective clothing without respiratory protection based on the scope and location of the work. Personnel dosimetry requirements consisted of a pocket ionization chamber (0 to 200 mR scale) and a thermoluminescent dosimeter (TLD) badge.

The workers entered the area and began installing new pipe. Operations continued smoothly until late in the afternoon when the workers discovered an out-of-service drain line interfering with installation of the new line. Unfortunately, they failed to observe a faded "**Caution: Radioactive Materials**" posting placed on the drain line. Because of the time, they decided to quit for the day.

The following morning, the workers informed their supervisor of the situation. The supervisor determined that work could not continue until a flanged pipe tee, connected to the drain line, was removed. Worker "A" attempted to remove the pipe tee, but, having difficulty loosening it, asked for assistance from Worker "B". After five minutes and considerable effort, the tee was successfully removed. Worker "B" observed that one of his gloves had been badly torn during this process, so he removed it and left it on the floor. He then spent a couple of minutes closely examining, touching, and measuring the end of the drain in order to locate a cap that would fit the exposed opening. Not finding an appropriate match, he decided to leave the end open. The two workers spent the following ten minutes one foot away from the old drain line while connecting another section of the new process line. After installation was completed, the workers departed the work area, removed their protective clothing, and performed whole-body frisking. Worker "A" was free of contamination; Worker "B" found contamination on his hands. A Radiological Control Technician (RCT) was notified.

List several concerns raised in this scenario.

***Your Solution:***

***Scenario 1, Part A Solution***

The scenario as presented raises several initial concerns. These include:

- Lack of a pre-job briefing.
- Inadequate administrative control. The significance of the change in the scope of the work went unnoticed. The RWP limited work activities to installing only a new drain line.
- Assigning either worker to this task considering the entrance to the building was posted as a high radiation and high contamination area. A higher level of training is typically recommended (see discussion from DOE 10 CFR 835 and the *Radiological Control Manual* below) for entry into these areas. In addition, Worker "A" required retraining. Even if this individual had the requisite training for entry into these areas, he should not have received authorization to reenter the area on the first day of the month.
- Failure of the work supervisor and the workers to adequately investigate and communicate the situation. While the workers notified their supervisor of the drain line obstruction, there is no indication that: (a) the RWP was reviewed to confirm the scope of the work, (b) the supervisor visually inspected the area, (c) the possibility of external radiation exposure or internal contamination from the pipe was discussed, (d) a radiological control technician was notified to survey the drain line before and after the pipe tee was removed.
- The faded radioactive materials posting which, if observed by the workers, could have alerted them and conceivably led to a minimization of the dose received.
- A lack of contamination control. The pipe tee was removed without the benefit of respiratory protection. Worker "B" also tore a glove and made no attempt to discard the glove in an appropriate manner, perform a contamination survey, and replace the glove.
- Failure to perform radiation surveys in a controlled area resulting in potentially higher exposures to the workers.
- The lack of health physics surveillance. There is no indication that health physics personnel were present in the building (or that portion of the building) to observe and curtail the operation if warranted.

10 CFR 835 contains several subparts and sections relevant to this scenario. Some of the pertinent requirements are noted below.

<u>Subpart E</u> (Monitoring in the Workplace)

Sections 835.402 and 835.404 address individual monitoring and radioactive contamination control and monitoring, respectively. Individual monitoring requirements essentially center around the use of personnel dosimetry. Section 835.402 requires personnel dosimetric devices for exposures to external radiation. Each worker presumably wore a pocket ionization chamber and a TLD badge based on the RWP requirements. The apparent lack of proper contamination control monitoring (by Worker "B" in particular) is a violation of 835.404.

<u>Subparts F and G</u> (Entry Control Program and Posting and Labeling)

Sections 835.501 and 502 address entries into radiological areas and high/very high radiation areas. Section 835.603 discusses posting requirements for radiological areas. The scenario as presented indicates that posting of the area was performed. Insufficient information exists as to whether all posting requirements and elements of the entry control program were addressed.

Subpart J (Radiation Safety Training)

Section 835.902 is devoted to radiation safety training for radiological workers. This section states requirements for training and retraining at intervals not to exceed two years. In the above scenario, retraining requirements were violated by Worker "A". This section also requires training be commensurate with each worker's assignment. Since the workers were entering a posted high radiation and high contamination area, a higher level of training is inferred for these conditions.

DOE/EH-0256T (Revision 1), *Radiological Control Manual*, contains numerous statements that are applicable to this scenario and the concerns noted above. For example:

- Articles 122 and 123 address worker attitudes and responsibilities, respectively. The scenario offers some indication that proper respect for radiation and the responsibilities each worker has when dealing with radiation and radioactive materials needs to be reinforced.
- Article 125 discusses the conduct of radiological operations and recommends that a supervisor be "knowledgeable and inquisitive," ask questions regarding the scope of work, and assist in the development of appropriate procedures. In this case, the supervisor should have requested more information from the workers and considered undertaking a visual inspection of the work location.
- Article 126 notes that properly trained workers can perform "supplementary radiological surveys" when a radiological control technician is not present. These workers apparently did not have any radiological instrumentation with them and, as a result, did not perform surveys of any kind.
- Articles 221 and 338 advocate frisking when leaving contamination areas. Worker "B" performed this well enough to detect the presence of contamination on his hands.
- Articles 321 and 322 provide typical information that should be included on, and the rationale for using, an RWP, respectively. Article 324 offers insight into relevant components of a pre-job briefing.
- Article 313 discusses the attention and planning that should be promoted for infrequent or first-time operations. Included in this would be an ALARA review by an appropriate committee and increased line and management oversight. It is conceivable that additional pre-job planning might have limited the worker's exposure.

- Article 334 addresses the minimum recommendations for unescorted entry into a high radiation area. Four criteria should be met: completion of Rad Worker II training (with one exception noted in Article 632.5), training in the use of a survey meter, signatures on the RWP, and the use of personnel and supplemental dosimetry. Note that the two workers had completed Rad Worker I and additional training for access into high radiation areas. This additional training satisfies the first condition of Article 334. Both workers had signed the RWP. The workers had presumably been trained in the use of a survey meter, but no survey instruments were carried into the area and no surveys were ever performed. The workers carried personnel dosimetry, but no supplemental dosimetry.

  **NOTE:** Some consideration could conceivably be given to the fact that even though the door to the building was posted as a high radiation and high contamination area, the work took place in a part of the building where a radiation area existed. The workers did meet the requirements for work in a radiation area. Even so, Worker "A" should not have been allowed access on the following day.

- Recommendations for unescorted access into high contamination areas include Radiological Worker II training (no exceptions are given), signatures on the RWP, protective clothing and respiratory protection when specified on the RWP, pre-job briefings, and personnel dosimetry. Examining these five recommendations, the workers should not have been allowed access to the building because they had not completed Rad Worker II training. As mentioned previously, no pre-job briefing had occurred.
- Articles 631-633 discuss the Radiological Worker Training requirements for access to radiological areas.
- Article 641 advocates that training not only stress normal or routine operations, but also situations where radiological conditions change during the course of performing a particular work function. Dose rates, for example, could increase as the job proceeds, underscoring the importance of recognizing, evaluating, and anticipating changing conditions that could affect a worker's exposure. Training requirements for radiological control technicians and supervisors are specified in Articles 642-644.

***Scenario 1, Part B***

Following decontamination of Worker "B's" hand, the RCT performed a survey near the drain line. His instrumentation indicated a whole-body dose equivalent rate of 60 mrem/hr at a distance of 30 centimeters. The RCT observed that the open end of the drain line contained an unknown residue. Taking adequate precautions, he collected samples from the drain line; isotopic analyzes performed immediately after collection revealed the presence of plutonium-238 (Pu-238) and plutonium-239 (Pu-239) in the nitrate form. Because of the potential and concern for internal deposition of radioactive material, urine and fecal samples from both workers were obtained for the next several days. Results for Worker "A" were negative. Bioassay results for Worker "B" indicated an intake of 10 Bq of Pu-238 and 12 Bq of Pu-239.

1. What are some concerns raised in this scenario?

2. Estimate the whole body external dose equivalent received by Workers "A" and "B" due to exposure from the out-of-service drain line only.

   **NOTE:** To aid you in your calculation, assume the workers maintained a constant one-foot distance from the drain line and

   - each worker initially spent 5 minutes at the drain line discussing what to do about the pipe tee obstruction interfering with their work.
   - each worker spent 5 minutes attempting to remove the flanged pipe tee.
   - Worker "B" spent an additional two minutes examining the exposed drain opening.
   - each worker spent 10 minutes next to the drain line connecting another section of the new process line.

   The equation to calculate the external dose equivalent (H) is:

$$H = \text{dose equivalent rate} \times \text{time}$$

3. The simplest way to calculate the CEDE to an individual is to use the tables of exposure to dose conversion factors for inhalation or ingestion found in *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11 (EPA 520/1-88-020). The CEDE to an individual is calculated:

   CEDE = (Intake) (Dose Conversion Factor)

   Another way to calculate the CEDE to an individual is to use a ratio of the intake to the stochastic ALI (sALI). The sALI for a radionuclide is that amount of the nuclide, which if taken into the body by the specified route (inhalation or ingestion), would result in a CEDE of 5 rem. Thus, the CEDE may be calculated:

$$CEDE = \frac{I}{sALI} \; x \; 5 \; rem$$

   where:

   I = intake

   The simplest way to calculate a CDE to an organ or tissue is to use the tables of exposure to dose conversion factors for inhalation or ingestion found in EPA Federal Guidance Report No. 11. The CDE to an individual organ or tissue is calculated:

   CDE = (Intake) (Dose Conversion Factor)

   Another way to calculate the CDE to an organ or tissue receiving the largest dose is to use a ratio of the intake to the non-stochastic ALI (nALI). The nALI for a radionuclide is that amount of the nuclide, which if taken into the body by the specified route (inhalation or ingestion), would result in a CDE of 50 rem to an individual organ or tissue. Thus, the CDE to the organ or tissue for which the nALI is specified may be calculated:

$$CDE = \frac{I}{nALI} \; x \; 50 \; rem$$

   where:

   I = intake

   Utilizing the simple way, use the information and equations provided below to calculate the committed effective dose equivalent (CEDE) to Worker "B" and the committed dose equivalent (CDE) from these intakes.

| Table of Dose Conversion Factors (DCF) | | | |
|---|---|---|---|
| **Radionuclide** | **Class** | **CDE per Unit Intake (Sv/Bq)** | |
| ------ | ------ | Bone Surfaces | Effective |
| Pu-238 | W | 1.90E-3* | 1.06E-4* |
| Pu-239 | W | 2.11E-3* | 1.16E-4* |

* Taken from EPA Federal Guidance Report #11, p. 151

The equation to calculate the CEDE is:

$$H_{50,E} = (Intake)(\Sigma\, DCF)$$

The equation to calculate the CDE to bone surfaces is:

$$H_{50,BS} = (Intake)(\Sigma\, DCF)$$

4. What is the significance of the reported doses in terms of DOE limits?

***Your Solution:***

***Scenario 1, Part B Solution***

1. DOE 10 CFR 835 and the *Radiological Control Manual* address some of the concerns in this part of the scenario.
   - The faded radiological posting present on the drain line is a concern. According to 10 CFR 835, Section 601, signs shall be “clear and conspicuously posted”. Article 231 of the *Radiological Control Manual* states that postings should "alert personnel to the presence of radiation and radioactive materials," "be conspicuously posted and clearly worded," and "be maintained in a legible condition." The worker's failure to observe the posting is clearly not entirely their fault, but likely resulted in Worker "B" receiving a higher dose.
   - The reading of 60 mrem/hr at 30 cm qualifies as a radiation area under 10 CFR 835 Subpart A, Section 835.2 and as noted in Table 2-3 of the DOE *Radiological Control Manual*. Posting the drain line as a radiation area should have been performed under Article 234.
   - 10 CFR 835.402 requires monitoring in the workplace for exposures to internal radiation. Articles 136 and 361 from the *Radiological Control Manual* refer to the difficulty in measuring transuranic uptakes. For that reason, considerable attention should be paid to controlling and preventing internal exposures. Article 316 cites the need for appropriate engineering and administrative controls as primary and secondary methods, respectively, to limit internal exposures. Respiratory protection is the next resort. Because: (1) respiratory protection was not required on the RWP based on the original scope of work (no potential for airborne radioactivity was thought to exist), and (2) the significance in the change in job scope was not recognized by the workers or the work supervisor, respiratory protection was not utilized at the time the pipe obstruction was discovered, removed, and opened. As a result, one of the workers received an internal dose.
   - Annual allowable dose limits are provided in Subpart C, Section 202 of 10 CFR 835 and Article 213 of the *Radiological Control Manual*. While the whole body and organ limits were not exceeded in this case, the doses received by the workers were not maintained ALARA.

2. Calculating the external whole-body dose equivalent received by the workers can only be estimated in this case because there are uncertainties regarding: (a) general exposure rates in the shielded portion of the building where they were working (no information was provided), and (b) the workers' proximity to the drain line at any given time. A constant one-foot distance was chosen to simplify the calculation. Given these uncertainties, the whole body doses are estimated as follows:

   Worker "A"

   Worker "A" spent an estimated 20 minutes near the drain line. Therefore, the worker received a dose equivalent of:

   (60 mrem/hr) *x* (1 hr/60 minutes) *x* 20 minutes = **20 mrem**

   Worker "B"

   Worker "B" spent an additional two minutes near the drain line. The dose equivalent is:

   (60 mrem/hr) *x* (1 hr/60 minutes) *x* 22 minutes = **22 mrem**

3. The CEDE is calculated as follows:

   $H_{50,E}$ = [(10 Bq x 1.06E-4 Sv/Bq) + (12 Bq x 1.16E-4)]
   = 2.45 E-3 Sv = **0.245 rem (245 mrem)**

   The CDE is calculated as follows:

   $H_{50,B}$ = [(10 Bq x 1.90 E-3 Sv/Bq) + (12 Bq x 2.11E-3 Sv/Bq)]
   = 4.4 E-2 Sv = **4.4 rem**

4. Considering only the dose received from exposure to the drain pipe, neither the DOE annual whole-body limit of 5 rem (from both internal and external radiation) nor the organ/tissue dose limit of 50 rem was exceeded for either worker. A summary of the doses received by both workers is summarized in the table below.

**SUMMARY OF DOSES RECEIVED BY WORKERS**

| Worker | External Dose (mrem) | Internal Dose (mrem) | TEDE |
|---|---|---|---|
| A | 20 | ----- | 20 |
| B | 22 | 245 | 267 |

Worker "A" received an external dose of 20 mrem and no internal dose for a total effective dose equivalent (TEDE) of 20 mrem, while Worker "B" received a TEDE of 267 mrem (245 mrem internal and 22 mrem external). No information was provided in the scenario as to whether any facility administrative control limits (ACLs) were exceeded. The ALARA philosophy suffered in this instance, however; therefore, an ALARA review should be initiated to prevent this situation in the future.

***Scenario 2***

A worker at a DOE contractor facility is using an x-ray diffraction device to perform crystal-structure analysis in materials research. During a sample change, one of the worker's hands is inadvertently exposed to the primary beam.

1. What is the major hazard from this particular x-ray generating device?

2. What potential exposures and biological effects could result?

***Your Solution:***

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***Scenario 2, Solution***

1. The major hazard associated with x-ray diffraction units is the intense, localized exposure from the primary beam to the hands or the eyes that can occur during a change of samples or beam alignment. This scenario involves a situation where the sample could not be enclosed in a protective structure and a"shutter" was left open, exposing one of the worker's hands. (**NOTE:** This cannot occur in many of the new, interlocked units).

2. The primary beam is very small, but can result in intense fields on the order of several hundred thousand roentgen per minute (R/min). These exposure rates can produce severe dermatological injury and potential loss of fingers.

## 4. Suggested Additional Readings and/or Courses

Readings


- Argonne National Laboratory. (1988). *Department of Energy Operational Health Physics Training* (ANL-88-26). Argonne, IL: Author.
- Cember, Herman (1996). *Introduction to Health Physics* (3rd ed.). McGraw-Hill: New York.
- Gollnick, Daniel A. (1991). *Basic Radiation Protection Technology* (2nd ed.). Pacific Radiation Corporation: Altadena, CA.
- International Commission on Radiological Protection. (1977). *Recommendations of the International Commission on Radiological Protection* (ICRP 26). New York: Author.
- International Commission on Radiological Protection. (1991). *Recommendations of the International Commission on Radiological Protection* (ICRP 60). New York: Author.
- National Council on Radiation Protection and Measurements. (1993). *Limitation of Exposure to Ionizing Radiation* (NCRP Report No. 116). Bethesda, MD: Author.
- National Research Council, National Academy Press. (1990). *Health Effects of Exposure to Low Levels of Ionizing Radiation (*BEIR V Report). Washington, D.C.: Author.
- United Nations Scientific Committee on the Effects of Atomic Radiation. (1988). *Sources, Effects, and Risks of Ionizing Radiation* (UNSCEAR 1988 Report to the General Assembly). New York: Author.
- U.S. Environmental Protection Agency. (1987). *Radiation Protection Guidance to Federal Agencies for Occupational Exposure* (52 FR 2822). Washington, D.C.: Author.

- U.S. Environmental Protection Agency. (1988). *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11 (EPA 520/1-88-020). Washington, D.C. and Oak Ridge, TN: Author.


Courses

**NOTE:** See Appendix B for additional course information

- *Nuclear Physics/Radiation Monitoring* -- DOE
- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Fundamental Radiological Control,* sponsored by the Office of Defense Programs, DOE
- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Applied Radiological Control,* sponsored by the Office of Defense Programs, DOE
- *Applied Health Physics* -- Oak Ridge Institute for Science and Education
- *Radiation Protection Functional Area Qualification Standard Training* -- GTS Duratek

Other

Actions or situations were combined to create new incidents from the following references:

- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Applied Radiological Control, Lesson 12-i (Radiation-Generating Devices).* {**NOTE**: This reference is from a course sponsored by Defense Programs at the DOE}
- U.S. Department of Energy. (1996). *Operating Experience Weekly Summary. (96-17,* April 19 through 25, 1996. Final Report Number 1.). Washington, D.C., Office of Nuclear and Facility Safety.

**NOTES:**